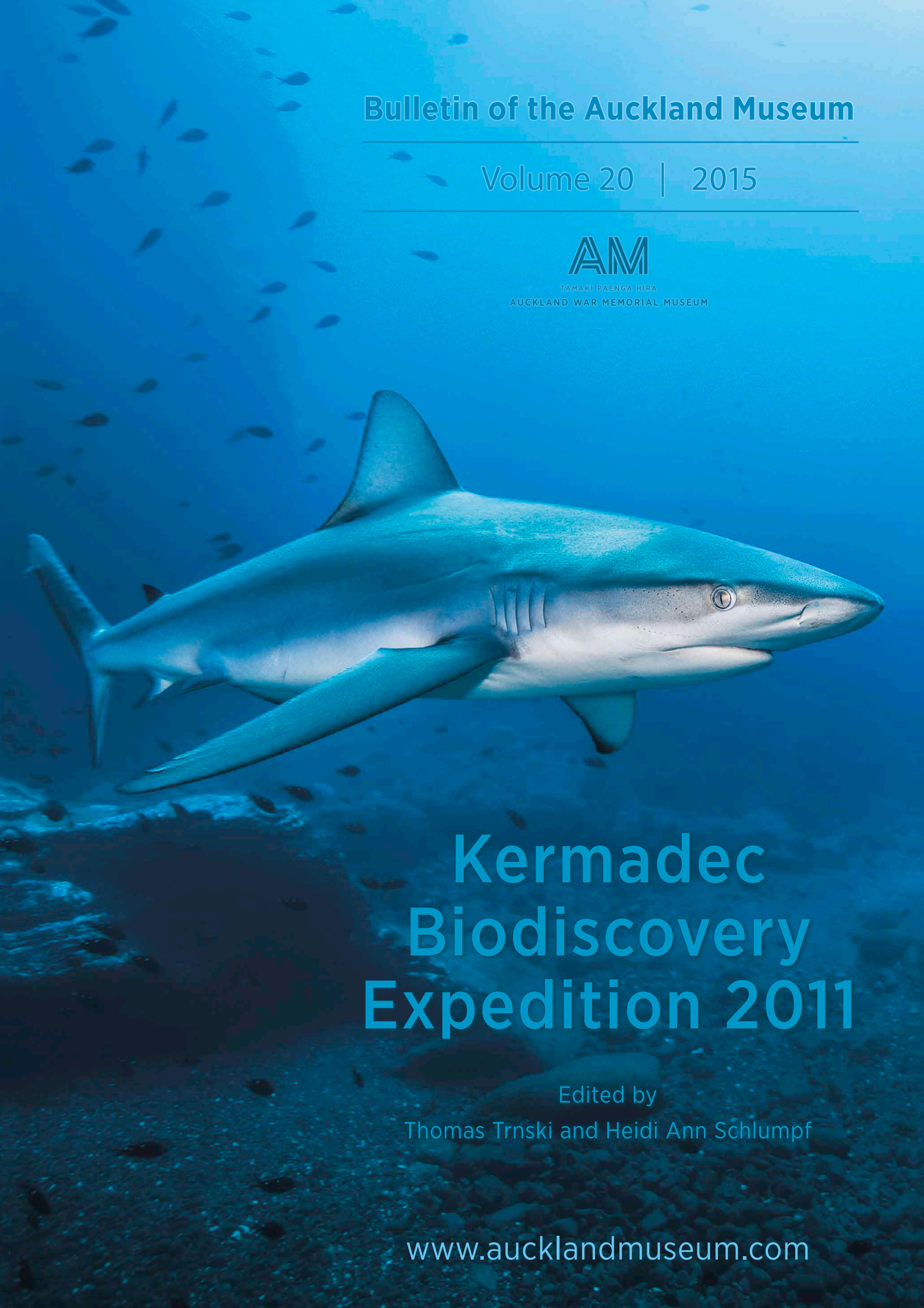




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# Kermadec Biodiscovery Expedition 2011

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# Obsidian from Macauley Island: a New Zealand connection

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## Abstract

An obsidian flake collected from Macauley Island during the Kermadec Expedition has been analysed to determine the source. The result indicates a Mayor Island, New Zealand, origin, supporting previous results on obsidian from Raoul Island that Polynesians travelled back into the Pacific from New Zealand.

## Keywords

obsidian; Pacific colonisation; Pacific voyaging; Macauley Island.

## INTRODUCTION

The Kermadec Islands comprise Raoul Island, the largest of the group, the nearby Meyer Islands and Herald Islets, and 100–155 km to the south are Macauley, Curtis and Cheeseman Islands, and L'Esperance Rock. Raoul is approximately 1000 km to the northeast of New Zealand. During the 2011 Kermadec Expedition, samples of naturally occurring obsidian were obtained from Raoul, the Meyer Islands, and from the sea floor off Curtis Island. These are now in the Auckland Museum collection. More importantly however was the single obsidian flake from Macauley Island, found within a lichen sample collected by botanist Peter de Lange (Figure 1). It is the first unequivocal evidence of a Polynesian presence on the island. This paper describes the sourcing study which attributes the obsidian to Mayor Island, a New Zealand source.

The archaeology of the Kermadec Islands was unknown prior to 1978 although adzes collected by the Bell family, who lived on Raoul from 1878–1914 (Johnson 1991:32), had been described. The eight adzes were clearly Polynesian in style but stylistically they did not favour an origin from any one island group over another (Duff 1968). The Kermadec Islands were uninhabited when sighted by Captain Sever of the convict transport *Lady Penrhyn* in 1788, but there was regular contact with Raoul Island by re-provisioning whaling vessels, and European occupation from the 1830s (Johnson 1991), so it could not be said conclusively that the adzes hadn't been brought to the island with later settlers. Active volcanism made Raoul Island, at times, an unattractive and precarious place to live and settlers were evacuated on occasion due to the volcanic activity.

The steep terrain meant there were only a few suitable habitation places confined to flat areas of limited size on the south and north coasts. The only landing places were adjacent to these flats. Botanical surveys have recorded the presence of Polynesian tropical cultigens including candlenut (*Aleurites monuccana*) and ti (*Cordyline fruticosa*) (Sykes 1977) which are not endemic to the island and it is assumed they were transported there by Polynesian settlers. Polynesian tuberous vegetables such as taro (*Colocasia esculenta*) and kumara (*Ipomoea batatas*) were also recorded but their introduction attributed to later 19th century immigrants.

An archaeological expedition to Raoul in 1978 explored the few flat areas suitable for prehistoric occupation (Anderson 1979, 1980). This was followed by a DOC-led expedition in 1990 (Johnson 1991, 1995). In Denham Bay there were historic settlement remains but no exposed evidence of earlier Polynesian occupation. On the north coast at Farm Terrace Polynesian occupation remains were found, but Low Flat had the most extensive occupation layer visible in the eroding scarp fronting the beach and also in the walls of gullies or ravines which intersected the flat. At least 1.5 m of dune sand or tephra from more recent eruptions covered the archaeological deposits. Investigations in 1978 revealed several earth ovens associated with bones of a sea mammal, postholes, shell midden, basalt flakes, two adzes and an imitation whale tooth pendant. The layer appeared to represent a single occupation (Anderson 1980), an interpretation confirmed by further investigation during the 1990 visit (Johnson 1991, 1995). Only a small amount of shell midden and faunal material was present in the layer but a candlenut found at the interface of the palaeosol (buried soil) and



Figure 1. Macauley Island showing the locations of the obsidian find and other possible cultural material.

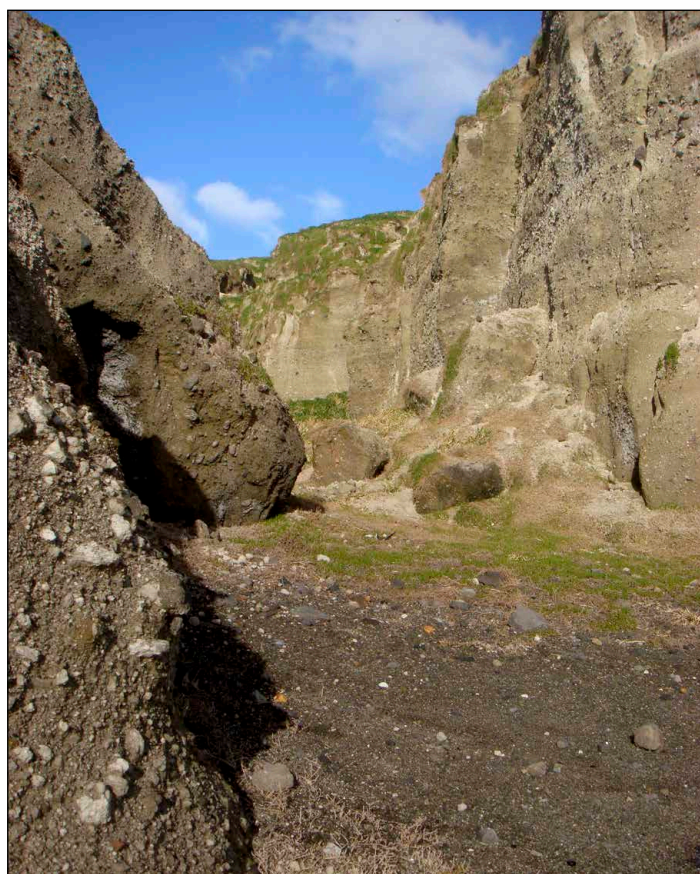


Figure 2. (left) Find location in Northern Access Gully, Macauley Island. *Photo: Peter de Lange.*

Figure 3. (above) Obsidian flake Macauley Island. *Photo: Kath Prickett.*

the cultural layer in 1990 may be highly relevant to discussions about Polynesian migration.

Six flakes and one core of highly vitreous obsidian, green in transmitted light, were recovered in 1978. Flakes similar to the naturally occurring obsidian were also present, but this material is greyish-black in transmitted light, dense, of poor flaking quality and easily distinguished from the green obsidian. During the 1990 excavations on Low Flat, several hundred flakes of Raoul Island obsidian were excavated but no further flakes of green obsidian were found.

Obsidian which is green in transmitted light has few known eastern Pacific sources. The flakes were twice subjected to sourcing studies using X-ray Fluorescence (XRF) and PIXE-PIGME analysis which compared the chemical signature of the flaked obsidian against a range of sources in New Zealand and elsewhere in the Pacific (Anderson and McFadgen 1990, Leach *et al.* 1986). Results confirmed the source as Mayor Island in the Bay of Plenty and raised the possibility of two-way voyaging between islands in Eastern Polynesia and New Zealand. The find of an imitation whale tooth pendant, stylistically similar to the form found in New Zealand and East Polynesia around the time New Zealand was colonised, confirmed an East Polynesian rather than a West Polynesian cultural origin although the island is closer to Ata in Tonga than it is to the Maori/Polynesian homeland islands in Central to East Polynesia.

## MACAULEY ISLAND

The island of 300 ha is the second largest in the Kermadec Group, and is about 110 km from Raoul Island. In good weather conditions Raoul can be seen from Macauley Island, but the reverse does not apply as Macauley Island is smaller and of lower elevation. Cliffs surround the island with the only suitable land access from a canoe at Sandy Bay on the eastern end. Unwelded ignimbrite to a depth of many metres overlies basalt exposed at sea level (Lloyd *et al.* 1996). Narrow steep-sided ravines dissect the interior plateau and in some places allow access to the coast which is strewn with large basalt boulders. The sides of the ravines erode easily in heavy rain events and tropical cyclones. In addition the island is subject to regular earthquakes which also affect the stability of the ravine walls. There is no running or standing water on the island. All of these factors make it an unfavourable place for occupation. The dominant vegetation now is *Hypolepis dicksonioides*, a fern which grows to 2 m in height and obscures the ground surface. This fern has thrived after removal of goats from the island in 1970 but there are indications that woody species such as Kermadec ngaio (*Myoporum rapense* subsp. *kermadecense*) and Kermadec poplar (*Homalanthus polyandrus*) are increasing in frequency, aided by the removal of Polynesian rats (*Rattus exulans*) in 2006 (P. de Lange pers comm). Petrels are abundant on the island and their burrows have severely modified the topsoil.

A lichen sample from Northern Access Gully (Figure 2), collected by botanist Peter de Lange, was later

found to contain an obsidian flake, green in transmitted light. No direct evidence of Polynesian occupation was found in exposed scarps at the rear of Sandy Bay during a visit in 1990, but a possible blade flake or cutter of local stone material was found above the cliffs at Sandy Bay (site KE/17) and small water-rolled cobbles found approximately 40 m above sea level (site KE/18, Southern Access Gully) were in a situation that suggested they had been transported there (Johnson 1995). Peter de Lange has advised that the location of KE/17 has since eroded and slumped onto Sandy Bay. The obsidian flake reported here, now in the Archaeology collection at Auckland Museum, is also out of context (and was probably washed into the Northern Access Gully after being ejected with soil from a petrel burrow in the near vicinity). The occupation evidence, if any surviving cultural layer is to be found, is probably sparse and highly disturbed. The physical conditions on the island, and the lack of safe canoe haul-out areas, make it unlikely Macauley Island was occupied but the obsidian flake, added to the more ephemeral evidence of a possible tool and water rolled pebbles found near or on access routes into the interior plateau from the sea, and the presence of the Polynesian rat (*Rattus exulans*), confirm Polynesian visitation.

The Macauley Island obsidian flake (Auckland Museum number 2012.10.1) was collected on 22 May 2011 from map ref. NZMS Topographic map 50 Kermadec Islands 589 544 ± 40 m. Maximum dimensions are 25 mm (length), 33 mm (width), 3 mm (depth), with a weight of 4.8 g (Figure 3). The flake is black in reflected light and olive green in transmitted light, has a vitreous lustre, very good (clear and glassy) translucency and there are two micro phenocrysts present. The flake has fractured choncooidally and has pronounced choncooidal bands. Although it appears to be a classic flake there is no striking platform and the bulbar scar is absent. The flake has a hinge termination. There is no unequivocal edge modification resulting from use or retouch but under x10 magnification short lengths of nibbled edge are visible which may indicate use or trampling.

## METHODS

Previous studies of New Zealand obsidian using PXRF instruments have been used to characterise and differentiate all known New Zealand geological sources (see Sheppard *et al.* 2011). This would suggest that such an analysis would be sufficient to characterise and determine the origin of the Macauley Island flake, as well as confirm the attribution of the material from the Low Flat site on Raoul Island.

The Macauley Island flake and eight of the obsidian flakes excavated from the Low Flat site on Raoul in 1977 (samples L.F.2, L.F.3, L.F.9 Surface, L.F.9 Sq6, L.F.9 Sq7, L.F.9 Sq8, L.F.9 Sq11-1, L.F.9 Sq11-2) were selected for PXRF analysis. The Raoul Island samples have previously been sourced using PIXE PIGME and XRF (Anderson and McFadgen 1990, Leach *et al.* 1986) and include those that have been assigned to the Raoul Island source and one sample which has previously been sourced to Mayor Island (L.F.9 Sq11-1).

Analysed alongside the archaeological samples were geological source samples from the Auckland University Anthropology Department Obsidian Reference Collection, and the collections of the Auckland Museum (see Appendix 1 for a description of the obsidian source samples in Auckland Museum. These are additional to descriptions of other Kermadec Islands source samples in Johnson 1995). The geological samples provided the geochemical profiles of the obsidian sources against which the archaeological material was compared. Ten samples of Kermadec Islands obsidian: Raoul Island (Hutchinson's Bluff, Bell's Ravine, p40908, p40908A); Macauley Island (MAC18A, MAC18E, MAC18D); the Herald Islets (South Meyer, South Meyer-2); and a single sample recovered from the sea floor in Stella Passage off Curtis Island were analysed. Samples from New Zealand obsidian sources were included and specifically those which produce green obsidians: Mayor Island (5.4-a, 9.1-a, 11.1-a); Waihi (32.1-a, 32.1-b, 32.1-c); Weta (25.2-a, 25.2 Otoroa, 25.2 Otoroa-2); Huruiki (31.7-a, Hu-1, Hu-1.2); and Kao (17.14, 17.14-a, 17.18-a). Three samples of Rapa Nui obsidian (Rano Kau 17503-a, Te Mamavai 17518 A, Maunga Orito 17691 B) were also analysed as in previous studies Rapa Nui obsidians have proved to be geochemically similar to the Mayor Island source.

The XRF analysis was carried out using the portable Innovox Delta Analyser housed at the University of Auckland. The machine operates using a four watt x-ray tube (Rh anode, Si-drift detector, 8–40keV, 5–200µA). All samples were analysed inside the laboratory stand provided by Innovox and using the instruments soil mode. This mode uses three beams run consecutively, each operating at different energies to detect either heavy elements, transition metals or light elements. Analysis time for each beam was set at 60 seconds. This configuration can detect the elements P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, As, Se, Zn, W, Rb, Sr, Zr, Mo, Hg, Pb, Bi, Th, U, Y, Nb, Ba. Analysis was limited to the elements Rb, Sr, Zr and Y, as these were sufficient for differentiating

the geological sources and are consistently detected with good accuracy and precision on this instrument.

All samples were placed with the flattest surface orientated towards the detector window in an effort to minimise the effects of surface irregularity on the results. All flakes analysed were large enough to cover the aperture window, eliminating the possibility that insufficient coverage would affect the results. The samples were oriented so surfaces with fewest inclusions were placed over the detector. However, given the extremely high inclusion content of some of the samples, especially those from the Kermadec Islands, it was not always possible to avoid them completely.

The NIST 278 powdered obsidian standard and the ANU 2000 Wekwok and Mayor Island 9.3 solid obsidian standards were run during the analysis sessions. Standards are useful for monitoring and assessing the accuracy and precision of the instrument. The averaged results of the standards for the elements used here, Rb, Sr, Zr and Y, are given in Table 1. The similarity of these values with the established values indicates that the instrument is reasonably accurate for these elements. Coefficients of variation were also calculated for these elements, all of which are under 5% indicating good precision (see Table 1). All values were corrected after analysis using a regression based on 29 standards calculated by Andrew McAlister (McAlister pers comm.).

## RESULTS

A bivariate plot of Zr vs Rb is given in Figure 4. The Macauley Island flake clearly groups very closely with the Mayor Island material and away from the other New Zealand, Easter Island and Kermadec Islands sources. Additionally, no strontium was detected for the Macauley Island flake. Such extremely low strontium concentrations are characteristic of the Mayor Island, Kao and Weta sources (Sheppard *et al.* 2011), while the Easter Island sources analysed in this study exhibit higher concentrations

Table 1. Averaged results for standard materials (NIST-278, ANU2000, Mayor Island 9.3).

(1 (Hollocher, Fakhry, and Ruiz 1995) 2 (Ambrose *et al.* 2009) 3 Analysed by WDXRF at the University of Auckland Geology Department (Sheppard pers comm.). \* analyses where strontium was not detected were excluded from the calculation of the coefficient of variation)

| Element ppm | NIST 278 (n=5) | SD    | CV    | Established Value <sup>1</sup> | Error | ANU 2000 Wekwok (n=5) | SD    | CV    | Established Value <sup>2</sup> | SD   |
|-------------|----------------|-------|-------|--------------------------------|-------|-----------------------|-------|-------|--------------------------------|------|
| Rb          | 128.917        | 2.173 | 0.017 | 133                            | 6     | 149.362               | 1.779 | 0.012 | 150.6                          | 2.9  |
| Sr          | 66.407         | 1.482 | 0.022 | 64                             | 5     | 72.171                | 2.306 | 0.032 | 61.1                           | 4.2  |
| Zr          | 299.254        | 4.786 | 0.016 | 290                            | 30    | 346.434               | 6.975 | 0.02  | 291.4                          | 14.5 |
| Y           | 46.177         | 0.75  | 0.016 | 39                             | 5     | 44.273                | 1.29  | 0.029 | 32.82                          | 1.6  |

| Element ppm | Mayor Island 9.3 (n=5) | SD    | CV     | Established Value <sup>3</sup> | Uncertainty |
|-------------|------------------------|-------|--------|--------------------------------|-------------|
| Rb          | 140.262                | 1.69  | 0.012  | 134                            | —           |
| Sr          | 6.362                  | 3.68  | *0.043 | 1                              | —           |
| Zr          | 1121.193               | 22.74 | 0.016  | 1028                           | —           |
| Y           | 142.946                | 2.22  | 0.012  | 118                            | —           |

at around 20 ppm, and the Kermadec Islands and Waihi sources exhibit much higher strontium concentrations, around 150–200 ppm. These results indicate that the Macauley Island flake is not from a Kermadec Islands source and strongly indicate that the Macauley Island flake should be assigned to the Mayor Island source.

Of the Low Flat site samples analysed, one flake L.F.9 Sq11-1 clearly also groups very closely with the Mayor Island source material and also exhibits a strontium concentration lower than the detection limit of the instrument, again suggesting that this flake should be assigned to the Mayor Island source. The other flakes from the Low Flat site group closely with the Kermadec Islands geological samples, specifically those from Raoul Island. These flakes also exhibit strontium and yttrium concentrations consistent with the Kermadec Islands

geological sources (Appendix 2) further suggesting that they are local Kermadec Islands obsidian and probably from the Raoul Island source.

A discriminant analysis was also carried out on all samples analysed using the elements Rb, Sr, Zr and Y and using the statistics package SYSTAT 12. The classification matrix for this analysis indicates that all of the geological sources considered in this study can be unambiguously discriminated on these four elements. For the archaeological material, this discriminant analysis assigns the Macauley flake and the Low Flat site sample L.F.9 Sq11-1 to the Mayor Island source with an associated probability of 100% (Table 2). All of the other archaeological material from the Low Flat site is assigned to the Raoul Island source with associated probabilities ranging from 79% to 99% (Table 2).

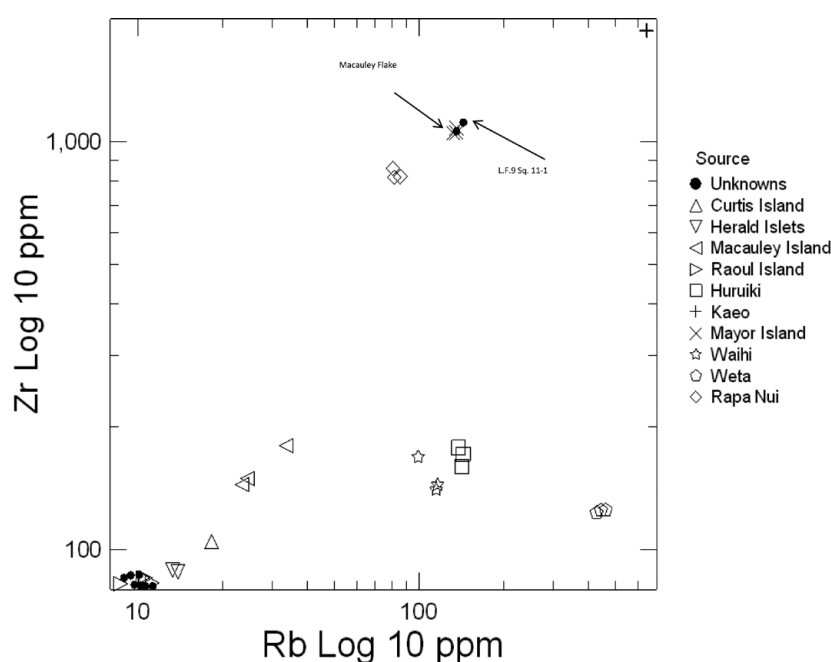


Figure 4. Bivariate plot of Zr vs Rb with all axes log 10 transformed.

Table 2. Associated probabilities for the discriminant analysis on the elements Rb, Sr, Zr and Y generated with SYSTAT 12.

| Sample ID      | Curtis Island/<br>Stella Passage | Herald Islets | Raoul Island | Mayor Island |
|----------------|----------------------------------|---------------|--------------|--------------|
| Macauley Flake | 0.000                            | 0.000         | 0.000        | 1.000        |
| L.F.2          | 0.005                            | 0.001         | 0.994        | 0.000        |
| L.F.3          | 0.022                            | 0.003         | 0.975        | 0.000        |
| L.F.9 Surface  | 0.000                            | 0.016         | 0.984        | 0.000        |
| L.F.9 Sq6      | 0.022                            | 0.002         | 0.976        | 0.000        |
| L.F.9 Sq7      | 0.002                            | 0.009         | 0.989        | 0.000        |
| L.F.9 Sq8      | 0.002                            | 0.204         | 0.793        | 0.000        |
| L.F.9 Sq11-1   | 0.000                            | 0.000         | 0.000        | 1.000        |
| L.F.9 Sq11-2   | 0.012                            | 0.001         | 0.987        | 0.000        |

## DISCUSSION

### Polynesian settlement of the Kermadec Islands

Previous researchers emphasised the importance of finding Mayor Island obsidian flakes on Raoul Island as it indicated voyaging back into tropical Polynesia was possible and, at least, partially successful. The four calibrated radiocarbon dates on shell from the Low Flat site on Raoul place occupation in the 14th century within the range of years AD1302–1326 which fits with the acceptable period for New Zealand settlement (Higham and Hogg 1997, Newnham *et al.* 1998). Thirteen dates on identified charcoal (reported in Anderson 1980; Higham and Johnson 1996) were not as clear cut and several results were rejected on the basis that pohutukawa (*Metrosideros kermadecensis*), potentially a long-lived tree, gave results older than other samples from the same layer. Reliable dates on charcoal of short-lived shrub species, when pooled, gave results with calibrated age ranges within the 14th century. Although the results on shell and charcoal do not overlap they are in general agreement, and the differences may be due to factors such as a small but unknown delta-R correction required for shell dates from the Kermadec Islands (Higham and Johnson 1996). The limited occupation evidence on Raoul strongly suggests Polynesian settlement of the island was for a relatively short period, and the island does not appear to have been reoccupied until historic times. Higham and Johnson (1996) further suggest the settlement at Low Flat may perhaps have been for only one or two decades.

The cultural evidence from Low Flat on Raoul Island suggests there was a single occupation and it is assumed the settlers carried cargo which included a suite of cultivated plants of which candlenut and ti are the only survivors. Anderson (1980) speculated the homeland was in the Society Islands. If the candlenut on Raoul was introduced by Polynesians in the 14th century, it is more likely that the island was settled directly from East Polynesia as the tropical candlenut would not have grown in the more temperate climate of New Zealand. The role Raoul played in Pacific voyaging is unknown, specifically whether it was an intermediary stopping-off place on voyages to and from New Zealand or there was a one-time visit from New Zealand on a return voyage to the homeland somewhere in East Polynesia. Regular contact between New Zealand and East Polynesia does not fit with the colonisation model that settlement was a one way voyage (Irwin 1992) although there is little dispute that there may have been colonisation by a number of canoes over a period of time. However Irwin (1992:110), in reviewing sailing technology, suggests canoes would most likely have sailed directly from East Polynesia to New Zealand but the prevailing easterly winds on a return voyage would have pushed them to the west, making landfall on Raoul more viable.

Macauley Island is small and not suitable for sustained occupation. The island has few attractions for settlement, and although there is naturally occurring obsidian it is of poor quality and not suitable for shaping into tools (Johnson 1995). Raoul, on the other hand, has

land which could be gardened, and there is abundant fish life in the waters surrounding the island without going further afield, making it more suitable as a base from which to explore and utilise resources on other islands. The main attraction of Macauley to Polynesians may have been the abundant petrels which could be extracted from burrows. Processing of petrels by cutting off the feet and wing tips prior to preserving the carcasses in fat was an activity identified in the Low Flat excavations (Anderson 1996), similar to the way mutton-birds and other bird species have been processed in New Zealand over a period of time. This energy rich food would have supplemented a diet of cultivated crops, wild foods, fish and shellfish.

At Emily Bay, Norfolk Island, 1300 km to the west of Raoul Island, archaeological excavations uncovered obsidian flakes with similar physical characteristics to the Raoul Island source (Turner *et al.* 2001: 63). The attribution was confirmed by XRF (Anderson *et al.* 1997). A single obsidian flake which was green in transmitted light and had a similar chemical element profile to Mayor Island obsidian was also present but XRF analysis was inconclusive as to it being from Mayor Island (Anderson, pers comm.). The radiocarbon dates from the Emily Bay site are indistinguishable from those of the Low Flat site on Raoul Island. Assuming the Emily Bay site is one of the first places to be occupied on Norfolk, it may have been settled by people associated with the site at Low Flat, who may in turn have had a direct knowledge of New Zealand or at the very least have been one generation removed from the settler population.

Settlement of Raoul and Norfolk Islands fits with the pattern of active Polynesian voyaging in the south eastern Pacific in the 14th century. Radiocarbon dates from sites in New Zealand, the Chatham Islands and from the Auckland Islands in the sub-Antarctic zone, indicate the 14th–15th centuries were one of widespread Polynesian exploration and discovery, when not only was the larger land mass of New Zealand settled but also significantly smaller islands. There is no evidence for direct voyaging from Raoul to New Zealand, although at least one waka travelled from New Zealand to Raoul carrying obsidian which was then used in daily activities. Interestingly there is no evidence from any of the islands of return voyaging, which is perhaps a reflection of how incomplete the archaeological record is.

## ACKNOWLEDGEMENTS

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## APPENDIX 1: Descriptions of Source Samples

### Raoul Island, Bell's Ravine.

Two surface areas of smooth cortex with a dull lustre, one grading into vitreous. Black to dark grey in reflected light, with weak flow bands of black and grey. In transmitted light the sample appears opaque as there are no thin edges, but under magnification there are areas of mid-light yellow- brown (“tea brown”). It has a fractured vitreous lustre. Xenocrysts, small clusters of olivine and plagioclase and individual plagioclase crystals, are abundant. There are occasional lithic inclusions of larger angular fragments of basalts. The microfractures and abundant xenocrysts cause the obsidian to fracture sub-conchoidally in the form of unpredictable angular shatter fragments.

Sample weight: 247 grams. Collected 18 May 2011 by Peter de Lange from alluvial outwash.

### South Meyer, Herald Islets

The cortex is vesicular on some surfaces, smooth on others. Colour is dark grey-black in reflected light and has opaque translucency. The lustre ranges from sub vitreous to waxy to dull. There are clusters of plagioclase and olivine in a finely crystalline vitreous groundmass. The fracture pattern is angular. A combined weight of seven sample fragments is 34 g. Found on a north ridge surface near a line of *Cordyline fruticosa* plants. Collected 13 May 2011 by Peter de Lange on the assumption that the material may be obsidian and therefore out of context with the Herald Islets geology. It has been identified however (Ian Smith pers comm.) as andesite with a sub vitreous lustre (high silica content), fitting with the basaltic andesite, andesite, andesitic dacite geochemistry of the islands.

### Curtis Island, Stella Passage

There is a variable cortex grading from smooth surfaces to almost vesicular and rough. The glassy matrix is black in reflected light and yellow brown in transmitted light. There are abundant xenoliths consisting of pale clusters of plagioclase and olivine in a black vitreous lusted glassy matrix. The curved sub spherical, micro fractured, structure of the material results in a crumbly perlitic fracture making it unsuitable for flake production. Sample weight 239 grams. Collected 25 May 2011 by Ged Wiren from the sea floor gravel and boulder bed close to shore. There were numerous cobbles of obsidian of similar appearance but a single specimen only was collected.

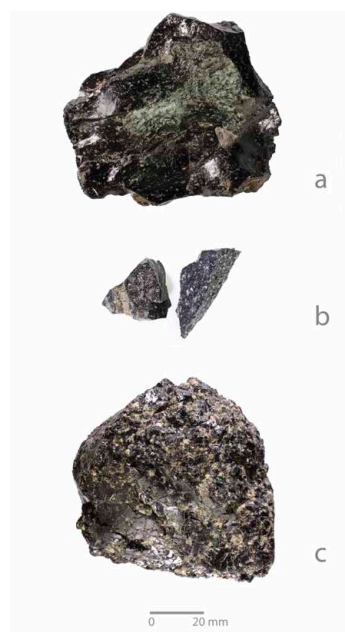


Figure. Source samples described in text. a. Bell's Ravine, Raoul Island; b. South Meyer; c. Curtis Island.

## APPENDIX 2: Elemental Data for All Archaeological Samples and Averages for the Geological Sources

\* Less than the limit of detection.

| Sample ID                     | Rb ppm | Sr ppm | Zr ppm  | Y ppm  |
|-------------------------------|--------|--------|---------|--------|
| Macauley Flake                | 136.42 | <LD*   | 1059.84 | 137.68 |
| L.F.2                         | 11.35  | 164.11 | 81.32   | 43.22  |
| L.F.3                         | 10.17  | 169.92 | 86.72   | 44.04  |
| L.F.9 Surface                 | 10.26  | 172.82 | 81.61   | 41.10  |
| L.F.9 Sq6                     | 10.66  | 167.98 | 81.32   | 44.63  |
| L.F.9 Sq7                     | 8.98   | 173.79 | 85.26   | 42.75  |
| L.F.9 Sq8                     | 9.48   | 187.33 | 86.43   | 43.69  |
| L.F.9 Sq11-1                  | 144.40 | <LD    | 1112.43 | 146.73 |
| L.F.9 Sq11-2                  | 9.77   | 167.02 | 81.90   | 44.04  |
| Herald Islets Average (n=2)   | 13.61  | 207.64 | 88.91   | 44.80  |
| Raoul Island Average (n=4)    | 10.26  | 171.37 | 84.16   | 43.22  |
| Stella Passage Sample         | 18.34  | 162.18 | 104.83  | 48.03  |
| Macauley Island Average (n=3) | 27.24  | 191.52 | 158.10  | 58.61  |
| Mayor Island Average (n=3)    | 134.98 | 1.96   | 1061.79 | 138.43 |
| Weta Average (n=3)            | 444.64 | <LD    | 124.50  | 106.47 |
| Huruiki Average (n=3)         | 141.21 | 41.21  | 169.93  | 43.88  |
| Kaero Average (n=3)           | 646.53 | <LD    | 1873.94 | 257.88 |
| Waihi Average (n=3)           | 110.32 | 171.82 | 151.33  | 17.41  |
| Easter Island Average (n=3)   | 82.81  | 23.32  | 833.92  | 170.23 |